

Changes in Temperature Profile, Texture and Color of Pork Loin Chop during Pan-frying

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Abstract

The aim of this work was to investigate changes in thermal profile, meat texture and color of pork chop during pan-frying with or without one turnover. Pork chops (1.2 cm thick) were individually pan-fried at 175 °C for 75 s without turnover or 150 s with one turnover. Internal temperature, meat color and texture at 11 designated positions were tracked. During frying, temperature and cooking loss significantly increased ($P < 0.001$), accompanied by a significant increase ($P < 0.001$) in hardness, gumminess, chewiness and L^* value, together with a significant decrease ($P < 0.05$) in springiness, cohesiveness, resilience and a^* value. Positions close to the periphery generally showed significantly higher ($P < 0.05$) final temperatures, and significantly lower ($P < 0.05$) hardness, gumminess, chewiness, L^* and a^* values than those close to the center. These results could explain variation in tenderness within the same sample when evaluating eating quality of cooked meat.

Keywords: color, thermal profile, pan frying, pork

Practical Applications

The paper showed significant differences in texture and color with different thermal transfer on different positions of the same pork steak. Color attributes show a certain relationship to texture and thermal transfer. It is possible to evaluate meat texture on the basis of color of cooked meat.

1. Introduction

Pan-frying is a very common cooking method for preparation of meat dishes and has an advantage of producing lower off-flavor without significant influence on other sensory attributes (pork flavor, tenderness, juiciness), compared to other high-temperature cooking method, e.g. grilling (Prestat, Jensen, McKeith, & Brewer, 2002). Frying temperature is a very important factor in terms of meat flavor, cooking time and weight loss of products. Meinert, Andersen, Bredie, Bjerregaard and Aaslyng (2007) showed that lipid-derived volatiles dominated when samples were fried at 150 °C but Maillard-reaction derivatives prevailed when samples were fried at 250 °C. However, too high frying temperature could induce the formation of heterocyclic amines in meat products and 175 °C could be the upper limit when the safety of meat products is taken as granted (Skog, Steineck, Augustsson, & Jagerstad, 1995).

Thermal profile and weight loss of meat products during cooking has been extensively studied (Ikediala, Correia, Fenton, & Ben-Abdallah, 1996; Zorrilla & Singh, 2003; Goni & Salvadori, 2010). Ikediala et al. (1996) mathematically modeled heat transfer in meat patties during single-sided pan-frying with or without turnover and

showed a difference in temperature change on bottom side, midpoint and top side. Zorrilla and Singh (2003) modeled a two-dimension thermal transfer profile during double-side cooking of meat patties, i.e., heat transfer occurred radially from the periphery to the midpoint and axially from the bottom and top sides to the middle. Goni and Salvadori (2010) also modeled temperature profile and weight losses during meat roasting. These studies gave us a good knowledge of heat and mass transfer during meat cooking. However, less has been known about changes in meat texture and color with heat and mass transfer during frying of pork chops.

Therefore, the objective of the present study was to investigate changes in thermal profile, meat texture and color during pan-frying of pork at 175 °C for 150 s with one turnover at 75 s.

2. Materials and Methods

2.1 Sampling

Five *longissimus* muscles between the first thoracic and the last lumbar vertebrae were removed from pig carcasses at approximately 8 h postmortem from a local market. Before sampling, hot carcasses were placed at 15 °C in which the onset of rigor mortis of muscle may be completed because pH values of muscle were around 5.6. Under this condition, cold shortening could be avoided (Savell, Mueller, & Baird, 2005). Each *longissimus* muscle was divided into 12 pieces of 1.2 cm-thick chops perpendicular to muscle direction.

2.2 Pan-frying

To investigate changes in temperature profile, meat texture and color inside pork chop before and after turnover, two trials were included.

In Trial 1 (frying for 75s, without turnover), 6 chops from the same animal were individually fried in 175 °C rapeseed oil (oil layer was approximately 1 mm thick) in a flat-bottomed frying pan for 75 s. During frying, muscle temperatures were tracked at 1 s interval with two temperature probes (Pt 100, Testo AG, Germany) connected with a Testo thermometer (Testo 735-2, Testo AG, Germany) at 11 different positions on the 6 mm-thick plane (Figure 1). The temperatures of 11 designated positions were tracked on 6 different chops with 1 or 2 positions each time (Table 1). After frying, chops were chilled to room temperature (15 °C) and cooking loss was calculated as the percentage of chop weight loss before and after frying. Then cooked chops were cut into two pieces at 6 mm thickness for further meat color and texture measurements.

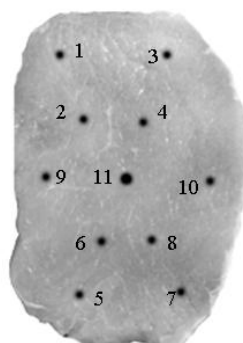


Figure 1. Positions selected for temperature, texture and color measurements

Table 1. Experimental design (N=5)

Trial 1	Trial 2	Temperature	Color	Texture
Chop 1	Chop 7	1, 2	1 to 11	1 to 11
Chop 2	Chop 8	3, 4	1 to 11	1 to 11
Chop 3	Chop 9	5, 6	1 to 11	1 to 11
Chop 4	Chop 10	7, 8	1 to 11	1 to 11
Chop 5	Chop 11	9, 10	1 to 11	1 to 11
Chop 6	Chop 12	11	1 to 11	1 to 11

In Trial 2 (frying for 150 s, with one turnover at 75 s), another 6 chops from the same animal were fried in the above medium on one side for 75 s and then on the other side for another 75 s. Temperature at the same positions

were tracked as described in Trial 1 before and after the turnover. Weighing and cutting were also done as above described.

2.3 Color Measurement

After cutting, newly cutting surface of cooked samples was bloomed in the air for approximately 20 min. Meat color at 11 designated positions was measured with a Minolta colorimeter (CR-300; Minolta Camera Co., Osaka, Japan) with illuminant D65, a 0° viewing angle and an 8 mm port/viewing area. Before measurement, the colorimeter was calibrated with a white tile (mod CR-A43). Color coordinates (CIE L*, a*, b*) were recorded.

2.4 Texture Analysis

Texture of cooked samples was analyzed with a TA. XT *plus* texture analyzer (Stable Micro Systems Ltd., Godalming, UK) on the cutting surface of the fried half part in Trial 1 and of the first fried half part in Trial 2. Meat samples were penetrated with a 5.0 mm-diameter cylinder stainless probe (P5) by a trigger force of 0.02 N at an acquisition rate of 200 pps (point per second). The test parameters were set as follows: pre test speed, 2.0 mm/s; test speed, 0.5 mm/s; post test speed, 5.0 mm/s. The penetration distance was 5.0 mm. Texture profile (hardness, springiness, gumminess, chewiness and resilience) was analyzed with the software Texture Expert Exceed (Stable Micro Systems Ltd, Godalming, UK).

2.5 Statistical Analyses

Principle component analysis (PCA) was performed with the program Unscrambler X (version 10.1 CAMO software AS, Oslo, Norway, 2010) to investigate the differences in texture and color among designated positions in all samples. All the variables were standardized by multiplying by 1/SD and seven components were selected. On scores plot, samples were grouped by designated positions.

Effect of position on muscle temperature, texture and color attributes were evaluated by one-way analysis of variance. Least squares means of 11 positions were compared by Bonferroni's method at the significance level of 0.05 (Abdi, 2007) with the program SAS 8.12 (2003).

3. Results

3.1 Thermal Change and Cooking Loss during Frying

Changes in muscle temperature at 11 designated positions were shown in Figure 2. Thermal change in chops during the first frying stage (before turnover) in Trial 2 was similar to that in Trial 1, and thus only results in Trial 2 was shown here. Positions close to the periphery (positions 1, 3, 5, 7 and 10) showed higher ($P < 0.05$) temperature than those close to the center (positions 2, 4, 6, 8 and 11) at the first stage (before turnover). At the second stage (after turnover), the temperature differences between positions close to the periphery (positions 1, 3, 5, 7, 9 and 10) and those close to the center (positions 2, 4 and 11) increased ($P < 0.05$).

Cooking loss of pork chops increased with frying time. Cooking loss after 150 s frying was twice as high as that of 75 s frying ($24.75 \pm 3.00\%$ vs. $11.26 \pm 2.19\%$ for 150 s and 75 s, respectively, $P < 0.001$).

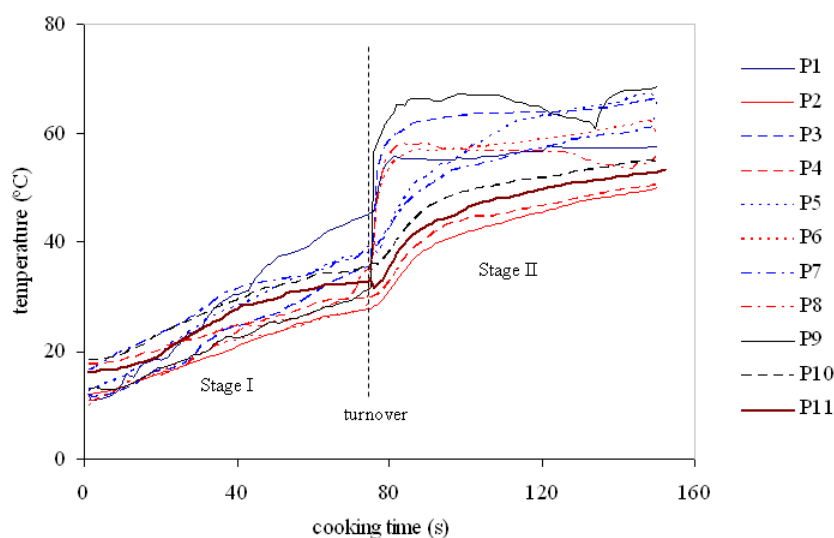


Figure 2. Thermal profile during frying with one turnover at 75 s

3.2 PCA Analysis

Principle component analysis showed that the first three components accounted for 91.6% of variations in color and texture variables in Trial 1 and 71.3% in Trial 2 (Figure 3).

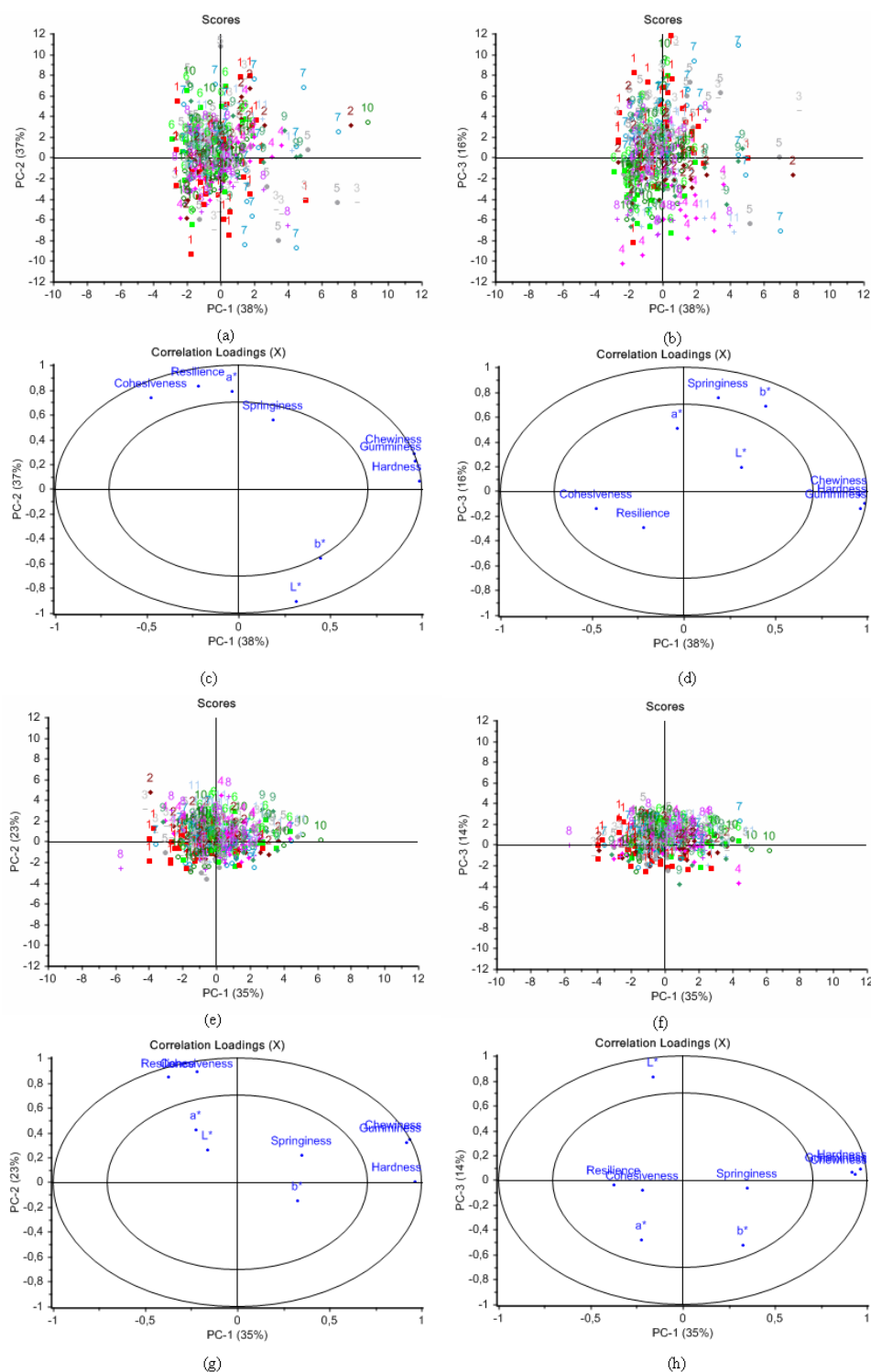


Figure 3. Principle component analysis of texture and color data

(a) to (d) for Trial 1: (a) scores plot (PC1 and PC2); (b) scores plot (PC1 and PC3); (c) correlation loadings plot (PC1 and PC2); (d) correlation loadings plot (PC1 and PC3)

(e) to (h) for Trial 2: (e) scores plot (PC1 and PC2); (f) scores plot (PC1 and PC3); (g) correlation loadings plot (PC1 and PC2); (h) correlation loadings plot (PC1 and PC3)

In Trial 1, PC1 accounted mainly for variations in hardness, gumminess and chewiness (Figure 3 c and d), PC2 for color attributes (CIE L*, a*, b*), resilience and cohesiveness (Figure 3 c), and PC3 for springiness and b* (Figure 3d). Positions 2, 9, and 10 showed great variation in the first dimension (PC1, Figure 3a and b), but positions 1, 6 and 8 varied mainly along with the second dimension (PC2, Figure 3a) and positions 4 and 8 varied along with the third dimension (PC3, Figure 3b). Positions 3, 5 and 7 varied in both the second and third dimensions (PC2 and PC3, Figure 3a and b). Position 11 showed small variation among individual samples.

In Trial 2, PC1 also accounted mainly for the variations in hardness, gumminess and chewiness, PC2 for resilience and cohesiveness, and PC3 for L*. In the selected three dimensions, all positions seemed to vary less, compared to those in Trial 1.

3.3 Meat Texture

At the first stage (Trial 1), several positions showed significant differences in springiness ($P<0.001$), cohesiveness ($P<0.001$) and resilience ($P=0.016$). Springiness seemed slightly higher at the positions close to the periphery (positions 1, 3, 5, 7 and 9) than those close to the center (positions 2, 4, 6 and 8), with the lowest value at position 8 and the highest at position 7 ($P<0.05$, Table 2). However, cohesiveness and resilience at positions 1, 3, 5, 7 and 9 were slightly lower than those at positions 2, 4, 6, 8, 10 and 11. Cohesiveness was the lowest at position 3 and the highest at positions 6 and 11 ($P<0.05$, Table 2). Resilience was the lowest at positions 3 and 7 and the highest at positions 2, 6, 10 and 11 ($P<0.05$, Table 2). Hardness, gumminess and chewiness did not show significant difference among the 11 designated positions ($P>0.05$).

At the second stage (Trial 2), hardness, gumminess and chewiness increased greatly ($P<0.001$), but springiness, cohesiveness and resilience declined ($P<0.05$). There were significant differences in hardness ($P<0.001$), springiness ($P=0.006$), gumminess ($P<0.001$) and resilience ($P=0.005$) among different positions. Hardness, gumminess and chewiness at positions 1, 3, 5 and 7 were numerically lower than those at positions 2, 4, 6, 8, 9, 10 and 11, with the lowest value at position 1 and the highest value at position 6 ($P<0.001$, Table 2). Springiness at positions 1, 5 and 10 was lower ($P<0.05$) than that at positions 3, 6 and 8. Resilience was the highest at position 11 and the lowest at position 7 ($P<0.05$). Cohesiveness was not significantly different ($P>0.05$) among all the designated positions.

Table 2. Changes in meat texture and color attributes of pork chop during pan-frying (Means $\pm$ standard errors, N=5)

Items	Positions											SE	P value
	1	2	3	4	5	6	7	8	9	10	11		
Frying for 75s without turn-over													
Hardness (N)	2.72	2.84	2.99	2.81	2.85	2.61	3.05	2.57	2.74	2.69	2.64	0.23	0.442
Springiness	0.85 ^{ab}	0.83 ^{ab}	0.85 ^{ab}	0.82 ^{ab}	0.86 ^{ab}	0.83 ^{ab}	0.87 ^a	0.81 ^b	0.84 ^{ab}	0.82 ^{ab}	0.86 ^{ab}	0.01	<0.001
Cohesiveness	0.68 ^a	0.70 ^{ab}	0.67 ^a	0.69 ^{ab}	0.70 ^{ab}	0.72 ^b	0.70 ^{ab}	0.69 ^{ab}	0.69 ^{ab}	0.70 ^{ab}	0.72 ^b	0.01	<0.001
Gumminess	187.12	200.49	200.52	197.01	197.65	189.95	211.64	178.08	191.27	191.72	192.94	14.87	0.658
Chewiness	160.82	166.92	171.44	161.27	170.67	157.94	185.56	144.62	161.21	157.84	166.89	12.68	0.204
Resilience	0.28 ^a	0.30 ^b	0.28 ^a	0.29 ^{ab}	0.29 ^{ab}	0.30 ^b	0.28 ^a	0.29 ^{ab}	0.29 ^{ab}	0.30 ^b	0.30 ^b	0.005	0.016
L*	60.77	57.65	63.05	65.11	60.92	63.3	62.93	66.16	67.19	70.17	66.64	2.79	0.079
a*	13.08	13.04	12.72	11.34	11.18	11.67	13.31	10.1	11.61	9.49	11.50	1.20	0.141
b*	10.64	8.95	11.56	11.64	8.59	9.80	10.46	10.54	12.73	11.81	11.51	0.90	0.084
Frying for 150 s with one turn-over													
Hardness (N)	10.33 ^a	12.56 ^{bc}	11.46 ^{ab}	13.12 ^{bc}	12.01 ^{abc}	13.45 ^c	11.65 ^{abc}	12.33 ^{bc}	12.89 ^{bc}	12.76 ^{bc}	13.02 ^{bc}	0.51	<0.001
Springiness	0.77 ^a	0.81 ^{ab}	0.82 ^b	0.81 ^{ab}	0.79 ^a	0.82 ^b	0.80 ^{ab}	0.82 ^b	0.81 ^{ab}	0.79 ^a	0.81 ^{ab}	0.01	0.006
Cohesiveness	0.55	0.56	0.57	0.55	0.55	0.56	0.54	0.55	0.56	0.54	0.56	0.01	0.068
Gumminess	581.19 ^a	701.49 ^{bc}	656.96 ^{abc}	735.14 ^{bc}	668.06 ^{abc}	766.95 ^c	641.69 ^{ab}	690.09 ^{abc}	734.97 ^{bc}	701.52 ^{bc}	740.65 ^{bc}	28.04	<0.001
Chewiness	449.74 ^a	564.67 ^{bc}	541.43 ^{abc}	595.49 ^{bc}	530.13 ^{abc}	623.07 ^c	515.92 ^{abc}	559.46 ^{bc}	596.73 ^{bc}	554.04 ^{bc}	602.58 ^{bc}	24.67	<0.001
Resilience	0.22 ^{ab}	0.22 ^{ab}	0.22 ^{ab}	0.22 ^{ab}	0.21 ^{ab}	0.22 ^{ab}	0.19 ^a	0.21 ^{ab}	0.22 ^{ab}	0.21 ^{ab}	0.23 ^b	0.01	0.005
L*	72.23 ^a	73.52 ^{ab}	73.98 ^b	74.04 ^b	73.83 ^{ab}	74.59 ^b	73.97 ^b	74.90 ^b	73.58 ^{ab}	74.32 ^b	74.06 ^b	0.42	<0.001
a*	6.09 ^a	6.81 ^{ab}	6.50 ^{ab}	7.18 ^b	6.00 ^a	6.53 ^{ab}	6.13 ^a	6.68 ^{ab}	6.11 ^a	6.87 ^{ab}	7.08 ^{ab}	0.27	<0.001
b*	12.19	11.88	12.12	11.81	12.49	11.92	12.00	11.78	12.25	11.49	11.75	0.23	0.446

^{a,b,c} Means on the same row with different letters are significantly different ($P < 0.05$).

3.4 Meat Color and Crust Formation

At the first stage (Trial 1), meat color (L^* , a^* , b^*) did not show significant differences among all the positions ($P>0.05$, Table 2). However, there was a thin brown layer along with the periphery (Figure 4 c). Meanwhile, a layer of crust was formed on the surface that had a direct contact with oil and pan (Figure 4 b).

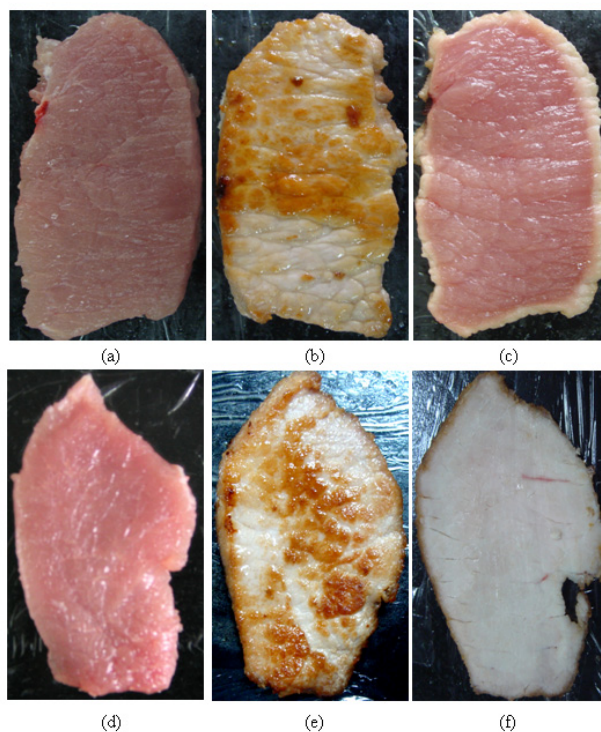


Figure 4. Meat color change and crust formation during frying

(a) and (d) raw meat; (b) and (e) crust formation; (c) and (f) cutting surface after 75 s and 150 s frying, respectively

At the second stage (Trail 2), the whole cutting surface became brown (Figure 4f) with much higher L^* value but lower a^* value ($P<0.001$, Table 2). Position showed a significant effect on L^* value ($P<0.001$) and a^* value ($P<0.001$). Lightness (L^* value) at position 1 was the lowest ($P<0.05$) but there was no significant difference ($P>0.05$) in L^* value among the other 10 positions. Redness (a^* value) at positions 1, 3, 5, 7 and 9 was numerically higher than that at other positions, with the highest value at position 4 ($P<0.05$, Table 2). There was no significant difference ($P>0.05$, Table 2) in b^* value among all the designated positions. In addition, crust was formed on both sides (Figure 4e).

4. Discussion

The main purpose of the present study was to investigate the variations in thermal transfer, texture and color at different positions of pork chop during pan-frying. To avoid the formation of heterocyclic amines that had been reported (Skog et al., 1995), we selected a moderate frying temperature (175 °C) and much shorter time (150 s).

On the basis of the final temperature, the doneness of 11 designated positions of the fried samples varied from medium (positions close to the periphery) to rare (positions close to the center), but the outermost layer could be very well done (AMSA, 1995). This could explain variation in texture and color as discussed below, and even shear force value or sensory tenderness score within the same sample when we evaluate eating quality of cooked meat. The temperature difference among positions in the present study was similar to Zorrilla and Singh (2003). During frying, thermal transfer took place from the cooking medium (oil) to the bottom side of meat sample (Zorrilla & Singh, 2003). At the same time, thermal transfer also happened from the hot air above the cooking medium to the periphery of pork chops (Zorrilla & Singh, 2003). Inside pork chops, thermal transfer continued mainly by water, as well as fat and proteins (Baghe-Khandan & Okos, 1981). However, water, fat and protein in muscle showed different thermal conductivity, with the highest for water (~0.65, conductivity increases with temperature below 70 °C), the lowest for fat (~0.16, conductivity decreases with temperature) and the

intermediate for protein (~ 0.19 , conductivity increases with temperature) (Baghe-Khandan & Okos, 1981). The positions close to the periphery received more heat than those close to the center and thus showed higher temperature.

During frying, hardness, gumminess and chewiness increased but cohesiveness decreased. This may be ascribed to moisture loss, denaturation of myofibrillar proteins and collagen shrinkage when meat temperature increased (Martens, Stabursvik, & Martens, 1982; Palka & Daun, 1999). In addition, the positions close to the periphery received more heat and had higher temperature than those close to the center. This would be expected to cause more myosin, actin and collagen susceptible to denaturation and shrinkage (Martens et al., 1982; Palka & Daun, 1999) and result in relatively high hardness, gumminess and chewiness at positions close to the periphery. Crust formation, which is typically characteristic of fried food (Sosa-Morales, Orzuna-Espiritu, & Velez-Ruiz, 2006), could also affect meat texture. However, the fact was opposite, which may be attributed to the absorption of more oil at those positions because a certain amount of oil would be absorbed in meat samples during pan-frying (Clausen & Ovesen, 2005).

During frying, L^* value increased but a^* decreased. This could be explained by heat-induced myoglobin degradation (a reduction in deoxyMb and oxyMb and an increase in globin haemochromogen, metMb and sulfMb) and the increase in the capacity to reflect the light (Fox, 1966; Garcia-Segovia, Andres-Bello, & Martinez-Monzo, 2007; Sosa-Morales et al., 2006). The differences in a^* values among 11 designated positions could be also explained by heat induced myoglobin degradation. Positions close to the periphery showed relatively low a^* value, which may be attributed to the formation of more globin haemochromogen and metMb (Sosa-Morales et al., 2006).

References

- Abdi, H. (2007). Bonferroni and sidok correlations for multiple comparisons. In, M. J. Salkind (ed.). *Encyclopedia of Measurement and Statistics*. Thousand Oaks, CA, Sage.
- American Meat Science Association (AMSA). (1995). Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. Chicago, IL: American Meat Science Association and National Live Stock and Meat Board.
- Baghe-Khandan, M., & Okos, M. R. (1981). Effect of cooking on the thermal conductivity of whole and ground lean beef. *Journal of Food Science*, 46, 1302-1305. <http://dx.doi.org/10.1111/j.1365-2621.1981.tb04159.x>
- Clausen, I., & Ovesen, L. (2005). Changes in fat content of pork and beef after pan-frying under different conditions. *Journal of Food Composition and Analysis*, 18, 201-211. <http://dx.doi.org/10.1016/j.jfca.2004.03.024>
- Fox, J. B. (1966). Chemistry of meat pigments. *Journal of Agricultural and Food Chemistry*, 14, 207-210. <http://dx.doi.org/10.1021/jf60145a003>
- Garcia-Segovia, P., Andres-Bello, A., & Martinez-Monzo, J. (2007). Effect of cooking method on mechanical properties, color and structure of beef muscle (M. pectoralis). *Journal of Food Engineering*, 80, 813-821. <http://dx.doi.org/10.1016/j.jfoodeng.2006.07.010>
- Goni, S. M., & Salvadori, V. (2010). Prediction of cooking times and weight losses during meat roasting. *Journal of Food Engineering*, 100, 1-11. <http://dx.doi.org/10.1016/j.jfoodeng.2010.03.016>
- Ikediala, J. N., Correia, L. R., Fenton, G. A., & Ben-Abdallah, N. (1996). Finite element modeling of heat transfer in meat patties during single-sided pan-frying. *Journal of Food Science*, 61, 796-802. <http://dx.doi.org/10.1111/j.1365-2621.1996.tb12205.x>
- Martens, H., Stabursvik, E., & Martens, M. (1982). Texture and color changes in meat during cooking related to thermal denaturation of muscle proteins. *Journal of Texture Studies*, 13, 291-309. <http://dx.doi.org/10.1111/j.1745-4603.1982.tb00885.x>
- Meinert, L., Andersen, L. T., Bredie, W. L. P., Bjerregaard, C., & Aaslyng, M. D. (2007). Chemical and sensory characterization of pan-fried pork flavor: interactions between raw meat quality, aging and frying temperature. *Meat Science*, 75, 229-242. <http://dx.doi.org/10.1016/j.meatsci.2006.07.004>
- Palka, K., & Daun, H. (1999). Changes in texture, cooking losses, and myofibrillar structure of bovine M. semitendinosus during heating. *Meat Science*, 51, 237-243. [http://dx.doi.org/10.1016/S0309-1740\(98\)00119-3](http://dx.doi.org/10.1016/S0309-1740(98)00119-3)
- Prestat, C., Jensen, J., McKeith, F. K., & Brewer, M. S. (2002). Cooking method and endpoint temperature

- effects on sensory and color characteristics of pumped pork loin chops. *Meat Science*, 60, 395-400. [http://dx.doi.org/10.1016/S0309-1740\(01\)00150-4](http://dx.doi.org/10.1016/S0309-1740(01)00150-4)
- SAS. (2003). Statistical Analysis Software for Windows (Version 8.12). SAS Institute Inc., Cary, NC, USA.
- Savell, J. W., Mueller, S. L., & Baird, B. E. (2005). The chilling of carcasses. *Meat Science*, 70, 449-459. <http://dx.doi.org/10.1016/j.meatsci.2004.06.027>
- Skog, K., Steineck, G., Augustsson, K., & Jagerstad, M. (1995). Effect of cooking temperature on the formation of heterocyclic amines in fried meat products and pan residues. *Carcinogenesis*, 16, 861-867. <http://dx.doi.org/10.1093/carcin/16.4.861>
- Sosa-Morales, M. E., Orzuna-Espiritu, R., & Velez-Ruiz, J. F. (2006). Mass, thermal and quality aspects of deep-fat frying of pork meat. *Journal of Food Engineering*, 77, 731-738. <http://dx.doi.org/10.1016/j.jfoodeng.2005.07.033>
- Zorrilla, S. E., & Singh, R. P. (2003). Heat transfer in double-sided cooking of meat patties considering two-dimensional geometry and radial shrinkage. *Journal of Food Engineering*, 57, 57-65. [http://dx.doi.org/10.1016/S0260-8774\(02\)00273-X](http://dx.doi.org/10.1016/S0260-8774(02)00273-X)